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Report Summary

In this report we present a summary on the methodology for uncertainty analysis of software reliability that was described in more details in the March 2002 report [Goseva02a] and September 2002 report [Goseva02d]. Within this methodology we considered several methods for uncertainty analysis: entropy, method of moments, and Monte Carlo simulation. In the September 2002 report on the *Application of the Methodology for Uncertainty Analysis on the Case Studies* [Goseva02d] we have presented the application and validation of our methodology on the case studies from the European Space Agency and NASA. In this report we compare entropy, method of moments, and Monte Carlo simulation accordingly to several criteria. Further, we present the future directions of our research on uncertainty analysis in software reliability.

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1. Overview of the methodology for uncertainty analysis

The architecture - based approach for software reliability assessment considers the utilization and the reliability of components, thus allowing insight into the dynamic behavior of software executions [Goseva01a]. In order to estimate the system reliability using architecture - based model we need to know the software architecture (structure of component interactions), software usage described by the operational profile (relative frequencies of component interactions determined by transition probabilities), and software failure behavior (component reliabilities or failure rates). In [Goseva01b] we have shown that the architecture – based software reliability model presented in [Cheung80] provides system reliability estimates close to the actual measured reliability, that is, we have validated the model appropriateness.

In the first year of this project (FY02) we have developed a methodology for uncertainty analysis of architecture - based software reliability models suitable for large complex component - based applications and applicable throughout the software life cycle. The methodology considers different approaches for building software architecture (intended approach and informed approach) and estimating component reliabilities (growth models, non-failed executions, and fault injection) as shown in Figure 1. Further, the methodology addresses the parameter uncertainty problem and enables us to study how the uncertainty of parameters propagates in the system reliability. Within this methodology we are considering several different methods for uncertainty analysis [Goseva02a]. So far, we have used entropy [Kamavaram02], methods of moments [Goseva02b], and Monte Carlo simulation [Goseva02c]. We have applied and validated our methodology on two case studies [Goseva02d]: software developed for the European Space Agency and NASA's Hub Control System (HCS) from the International Space Station (ISS).

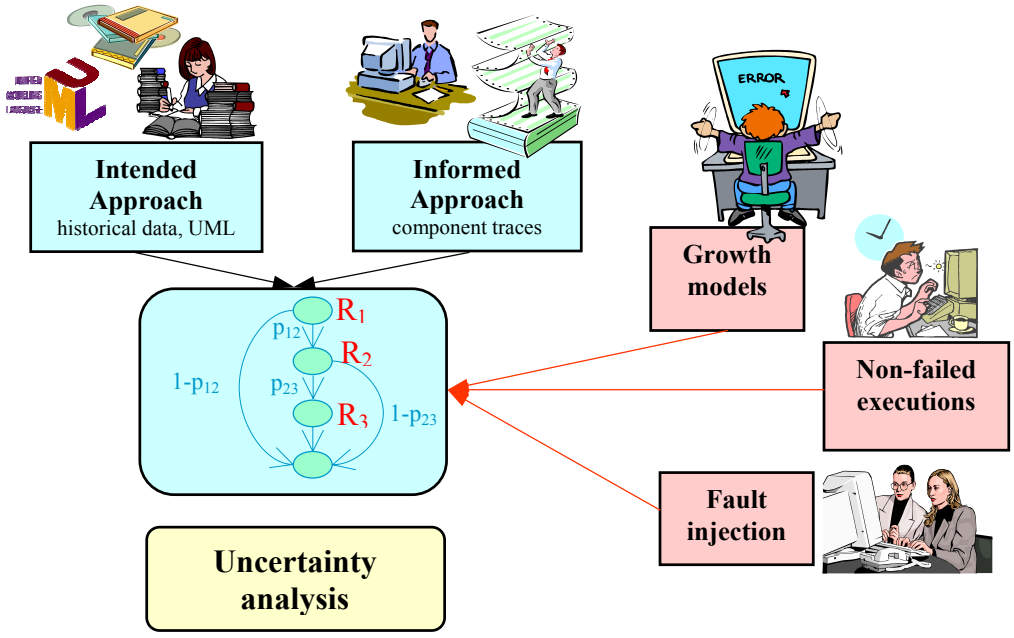

Figure 1. Methodology for uncertainty analysis of software reliability

2. Comparison of the methods for uncertainty analysis

Within our methodology we have considered several different methods for uncertainty analysis: entropy, method of moments, and Monte Carlo simulation. The analyst may choose the most suitable method for a particular application based on the following criteria:

- data requirements
- reliability measures derived
- accuracy of the solutions
- scalability with respect to the number of components.

Here we briefly summarize the methods of uncertainty analysis that we have considered so far with an emphasis on the above criteria.

2.1. Entropy

We used the well known concepts from the information theory, source entropy and conditional entropy, to quantify the uncertainty of the operational profile, the overall software reliability, and software components. The characteristics of the entropy as a measure for uncertainty are the following:

- *Data requirements*
  - Low: Point estimates of the transition probabilities and components reliabilities.
- *Reliability measures derived*
  - NA: Reliability measures are not derived. Instead, we derive the uncertainty of an operational profile and software reliability, as well as components uncertainties.
- *Accuracy of the solutions*
  - Exact analytical solution for the uncertainty (source entropy and conditional entropy)
- *Scalability*
  - Scales well. Could be used for large systems.

2.2. Method of moments

Method of moments is an approximate analytical method that allows us to estimate the moments of the system reliability based on the knowledge of the moments of component reliabilities. Its characteristics with respect to the different criteria are the following:

- *Data requirements*
  - Low: Only the moments of components reliabilities are needed, that is, no distribution function must be specified.
- *Reliability measures derived*
  - Moments of the system reliability (usually the mean and variance).

- *Accuracy of the solutions:*
  - Approximate method.
  - The accuracy may be increased by using higher order Taylor series.
  - The accuracy is not readily quantifiable.
  - Generation of random numbers is not required, therefore there is no sampling error.
- *Scalability*
  - Due to the computational cost for evaluating the Taylor series coefficients and system moments the use of the method is limited to medium size systems.

2.3. Monte Carlo simulation

The third method for uncertainty analysis that we have developed is based on simulation. The basic characteristics of the Monte Carlo simulation used for uncertainty analysis in software reliability are the following:

- *Data requirements:*
  - High: Probability distribution functions of modeling parameters (transition probabilities and components reliabilities).
- *Reliability measures derived*
  - Many characteristic of system reliability can be derived, including frequency charts, moments, percentiles, and distribution functions.
- *Accuracy of the solutions:*
  - Approximate method.
  - The accuracy may be increased by increasing the number of simulations (sample size). Although with the hardware available today it is not critical, it is worth mentioning that the computational cost increases with the sample size.
  - Sampling errors may be involved in case of long tail distribution.
- *Scalability:*
  - Scales very well, that is, it is not very sensitive to the number of components in the system. Could be used for large systems.

3. Make a choice table

In Table 1 we summarize the comparison of different methods presented in the previous Section. This so called "Make a choice" table provides a sound guideline for choosing the most appropriate method for a given software application.

Method	Data requirements	Reliability measures	Accuracy of the solution	Scalability
Entropy	Point estimates	NA	Exact analytical solution	Large systems
Method of moments	Moments of components reliabilities	Moments of system reliability	Approximate solution ▪ Accuracy may be increased by higher order Taylor series ▪ No sampling errors	Medium systems
Monte Carlo simulation	▪ Probability distribution functions of components reliabilities and transition probabilities ▪ Generation of random numbers	Many characteristics of system reliability ▪ Frequency chart ▪ Distribution ▪ Moments ▪ Percentiles	Approximate solution ▪ Accuracy may be increased by increasing the sample size ▪ Sampling errors may be involved in case of long tail distributions	Large systems

Table 1. Make a choice table: Comparison of different methods for uncertainty analysis

4. Future work

Our future work on uncertainty analysis of software reliability is focused on the following tasks:

- **Within the proposed methodology consider several additional methods for uncertainty analysis**

  In addition to the entropy, method of moments, and Monte Carlo simulation developed in FY02, in FY03 we will consider other methods for uncertainty analysis. These include exact analytical solution and perturbation analysis.

- **Compare all methods for uncertainty analysis developed in FY02 and FY03 and complete the "Make a choice" table**

  One of the main thrust of our future work is to compare different methods for uncertainty analysis accordingly to the following criteria: data requirements, reliability measures derived, accuracy of the solutions, and scalability with respect to the number of components. This comparison will help us to complete the "Make a choice" table which can be used as a sound guideline for choosing the most appropriate method for a given software application.

- **Apply and validate the methodology in general and different methods for uncertainty analysis in particular using NASA case studies**

Initially, we have applied and validated our methodology on the case study from European Space Agency. Recently, we have used the available artifacts of the NASA's Hub Control System (HCS) from the International Space Station (ISS) to illustrate and validate our methodology. Both case studies are presented as a part of the FY02 report from September 30, 2002 [Goseva02d]. In FY03 we intend to explore several other sources of data for case studies from NASA. These include SIAT tool from Titan Systems Corporation, testing tool for real - time systems developed at ASU, and the Mission Data System (MDS) at Jet Propulsion Laboratory.

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